Assumptions and Guidelines

The following summarizes key assumptions and guidelines made for this study.

- The primary criterion for selecting candidate implementations is reduction in operations cost.
- For the purposes of selection, only development costs are considered. Production and retrofit costs are treated at the system level.
- Fleet sizing is assumed to remain at four.
- Flight rate is assumed to be eight Space Shuttle flights per year.
- The new start would be in 1998.

Retrofit Alternative

A number of changes would be implemented in this alternative. They are illustrated in figure 10. A new thermal protection system (TPS) was proposed to replace one-third of all insulation tiles with a new toughened rigid ceramic tile. The areas selected were the damage-prone areas. In addition, changes were proposed to the thermal blankets, the tile bonding method, the tile gap fillers, and the hot body structure. The rudder/speedbrake and body flap were converted from a tile system to a hot body structure. The orbital maneuvering system (OMS)/reaction control system (RCS) propellant selection remained hypergolic monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4); however, both component reliability and accessibility were greatly improved.

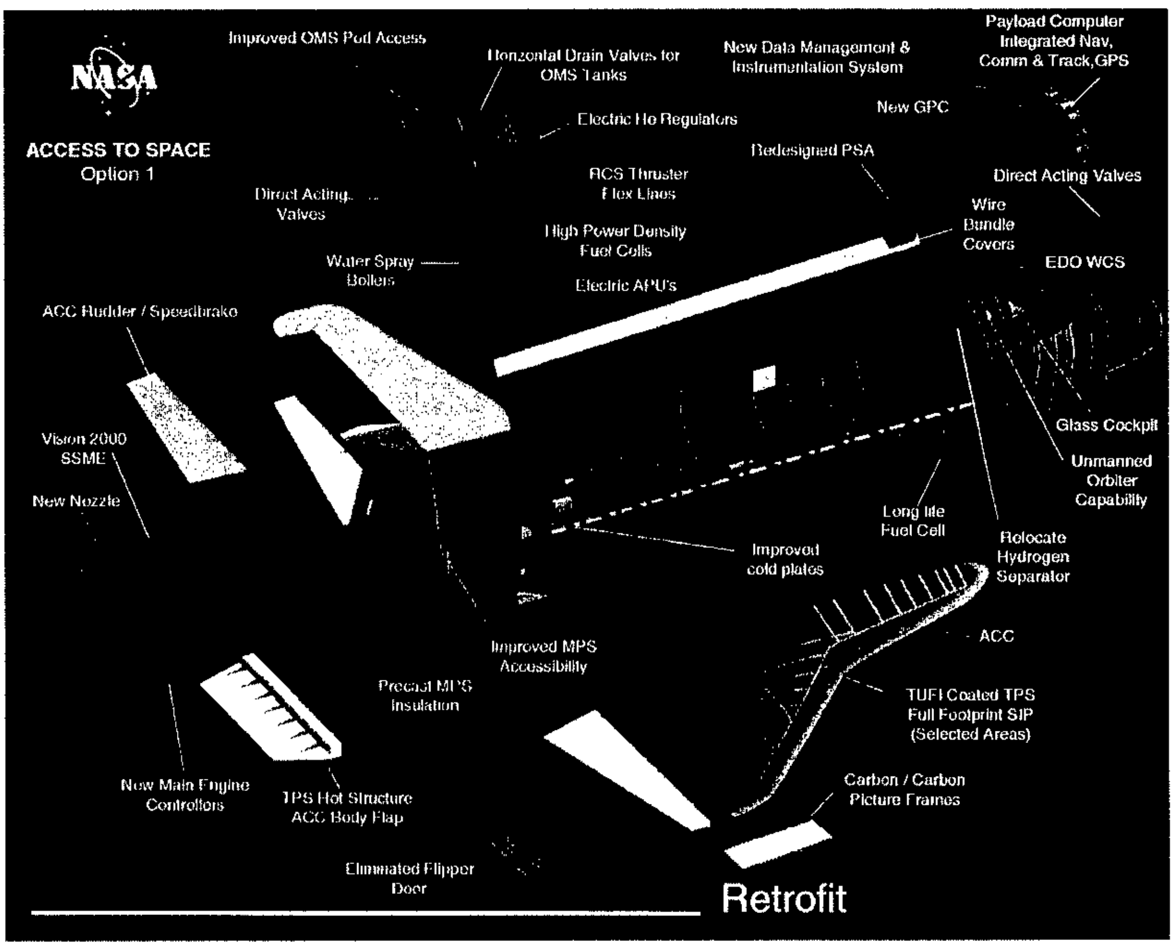


Figure 10.—Retrofit alternative.

The new avionics system includes a new integrated communication system, a new navigation system based on the Global Positioning System (GPS and differential GPS), and a new data management system. The new avionics system reduces the number of line replaceable units (LRU's) in the forward avionics bays, resulting in elimination of avionics bays 3a and 3b. The middeck lockers were relocated to where avionics bays 3a and 3b were, allowing improved accessibility into bays 1 and 2.

The new mechanical and electrical power system replaced the hydrazine auxiliary power system with an electrical-based auxiliary power system powered by three dedicated high-density fuel cells. In addition, changes were made to the hybrid load controller assemblies, the instrumentation power system, the fuel cells, and the electrical wire protection system. The major changes to the Environmental Control and Life Support System (ECLSS) were the addition of quick disconnects for easier access, elimination of the need for ground support equipment (GSE) cooling post-landing, and an assortment of other minor changes.

Modifications to the orbiter structure focused on replacement of the boron/aluminum struts on an attrition basis with more robust struts, the capability to inspect for corrosion on the rudder/speedbrake, and elimination of the wing flipper door replacement accomplished by modifications to the wing design.

Minor modifications were made to the orbiter's main propulsion system (MPS). The Space Shuttle main engine (SSME) was baselined to use the year-2000 configuration engine which includes advanced technology fuel and oxidizer turbopumps, a large throat main combustion chamber, a phase II powerhead and single coil heat exchanger, and block II controller improvements. In addition, a new main engine controller would be brought on-line.

The higher performance super-lightweight tank (SLWT) design would be used for the external tank (ET), along with an assortment of other modifications. The modifications to the solid rocket boosters (SRB's) included replacing the hydrazine auxiliary power unit (APU) with a solid propellant gas generator and utilizing laser-initiated pyrotechnics.

New Build Alternative

This alternative included many of the changes described for the Retrofit Alternative and, in addition, added the following changes—illustrated in figure 11—including enhancements to the thermal protection system, orbital maneuvering system/reaction control system, mechanical and electrical power system, Environmental Control and Life Support System, structural system, Space Shuttle Main Engine, and solid rocket booster.

The thermal protection system retrofitted all blankets and tiles with new improved blankets and toughened rigid ceramic tiles. The orbital maneuvering system/reaction control system was converted to an oxygen and ethanol-based propellant system. This new on-orbit propulsion system was designed to meet current volume envelopes, redundancy requirements, and on-orbit and entry impulse requirements.

The auxiliary power system was converted from a complete mechanical power system to an electro-mechanical actuator (EMA) system supplied by three dedicated high-density fuel cells. The Environmental Control and Life Support System replaced the ammonia boiler with a cryogenic boiler system. The structure was changed to incorporate a modified lower fuselage skin, additional access ports, and selected aluminum-lithium (Al-Li) replacements. The Space Shuttle main engine was converted from hydraulics to electro-mechanical actuation power. The solid rocket booster was converted from hydraulics to an electro-mechanical actuation system.

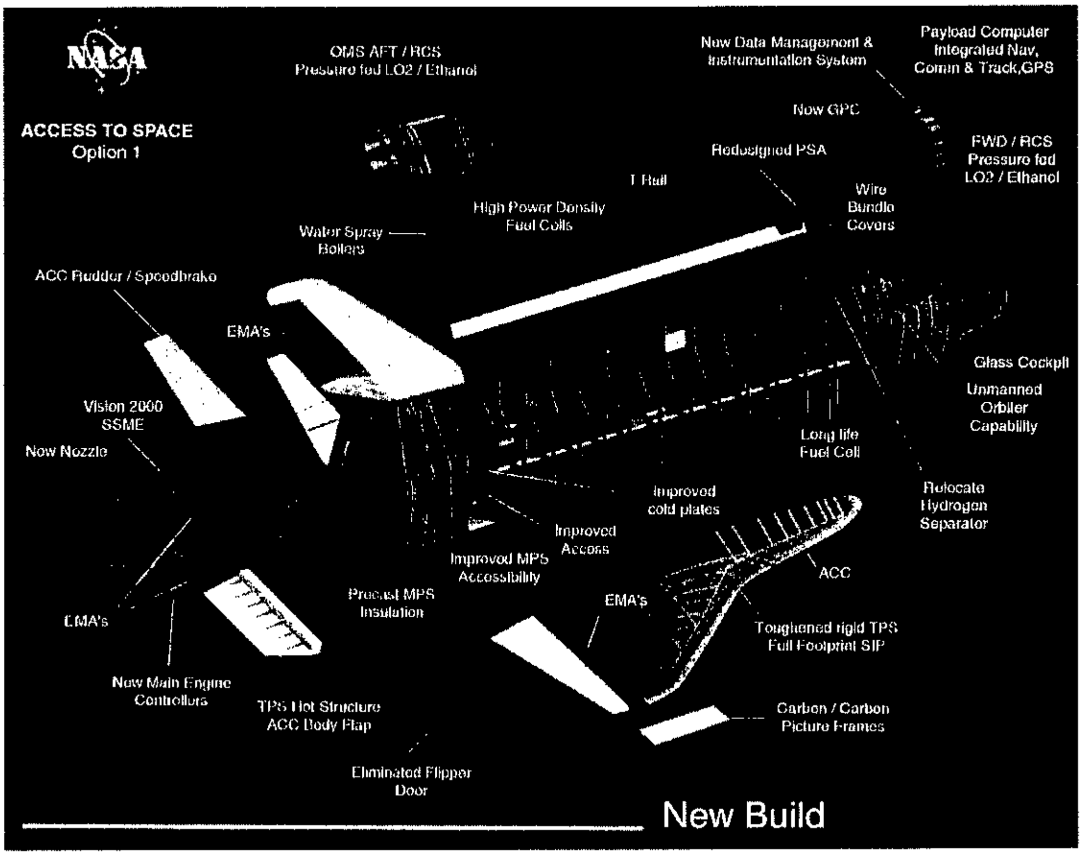


FIGURE 11.—New build.

New Mold-Line Alternative

For the New Build Alternative, orbiter winglets and canards were evaluated for improved entry performance. Movement of the Space Shuttle main engines to the bottom of the external tank was considered. The changes considered are illustrated in a typical configuration in figure 12. For the solid rocket boosters, a flyback liquid booster, expendable liquid boosters, and hybrid liquid/solid boosters were considered. The orbiter part of this alternative was discontinued prior to completion because no appreciable cost savings were identified for the improved performance. The movement of the Space Shuttle main engines was discarded quickly due to the significant increase in per-flight cost.

Expendable liquid boosters and hybrid liquid/solid boosters were ruled out because of the large increase in cost that was estimated by the Marshall Space Flight Center. Flyback liquid boosters were then evaluated separately as an add-on to either the Retrofit Alternative or the New Build Alternative, and work on the New Mold Line Alternative was discontinued. The flyback booster concept incorporated either a single or dual F–1 engine configuration and was able to return to a conventional landing field. The concept definition was insufficient to conduct a proper evaluation of its merits and requires additional work beyond the scope of this study. However, the concept appears attractive from many aspects, such as having a significantly lower theoretical minimum cost per flight than the current solid rocket booster, engine shutdown capability, synergy with orbiter systems (i.e., avionics, reaction control system, landing systems, etc.), and enhanced performance. These various booster options are illustrated in figure 13.

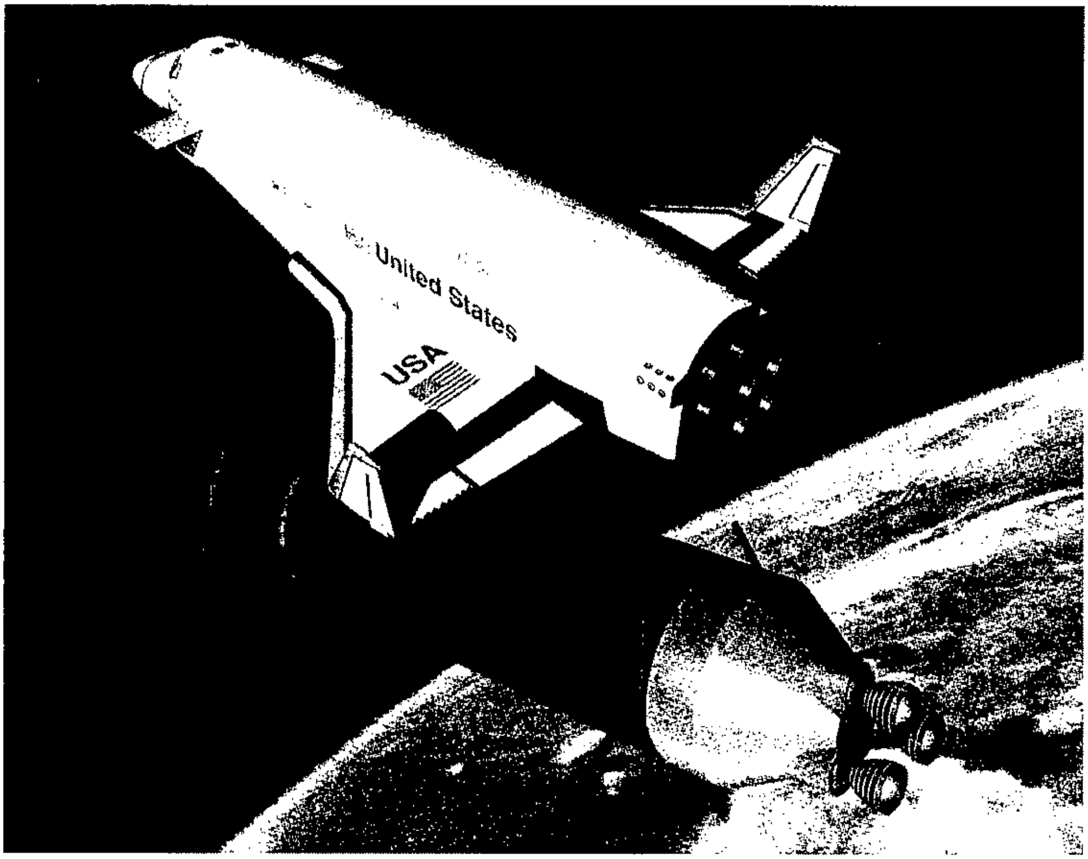
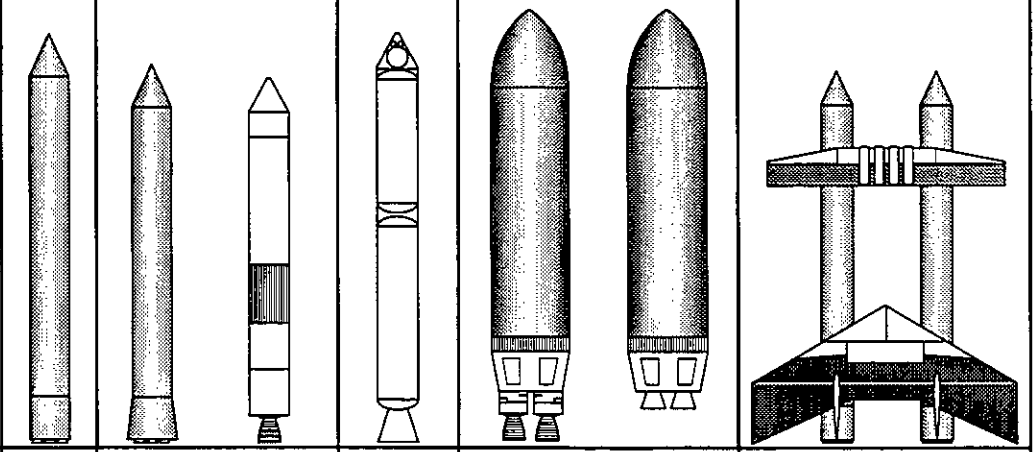


Figure 12.—New mold line.



	Option 1	Options 2 and 2A		Option 3	Options 4 and 4A		Option 5
Propellant	lox/LH_2	lox/RP–1	lox/RP–1	Hybrid	Reusable	Expendable	Flyback lox/RP–1
Engine Type	STME	STBE	F–1A	Pressure	SSME	STME	Hi PC Engine
No. Engines/Booster	4	4	1	1	3	3	4
Thrust SL (klbf)	518.6	513	1,800	2,887	375	552	660
Booster Diameter (ft)	18	15.3	14.7	17.0	ET	ET	15
Booster Length (ft)	178.1	151	148	170.2	ET	ET	147

Some of these options may be attractive. Requires further study.

STBE–Space Transportation Booster Engine

Figure 13.—STS booster/propulsion options.

Additional Means of Increasing Safety and Decreasing Cost

In addition to defining implementations for the above evolution alternatives, two additional systems were evaluated as add-ons. They were an auxiliary crew escape system and an uncrewed orbiter system. The approach for the crew escape system was to evaluate concepts that would provide a backup system for returning the crew for the full ascent phase of the mission. However, concepts that would work above 140,000 feet resulted in prohibitive weight/performance penalties. Therefore the study quickly narrowed in on concepts which would work below 140,000 feet. Three detailed concepts were defined. They were a five person ejection seat system, an eight person ejection seat system with an extended flight deck, and an eight person escape pod system. The mass penalties ranged from 1,746 pounds for the five person option to 7,588 pounds for the pod. The center of gravity was moved significantly forward in all three concepts, resulting in severe restrictions on payload placement. These alternatives are illustrated in figure 14.

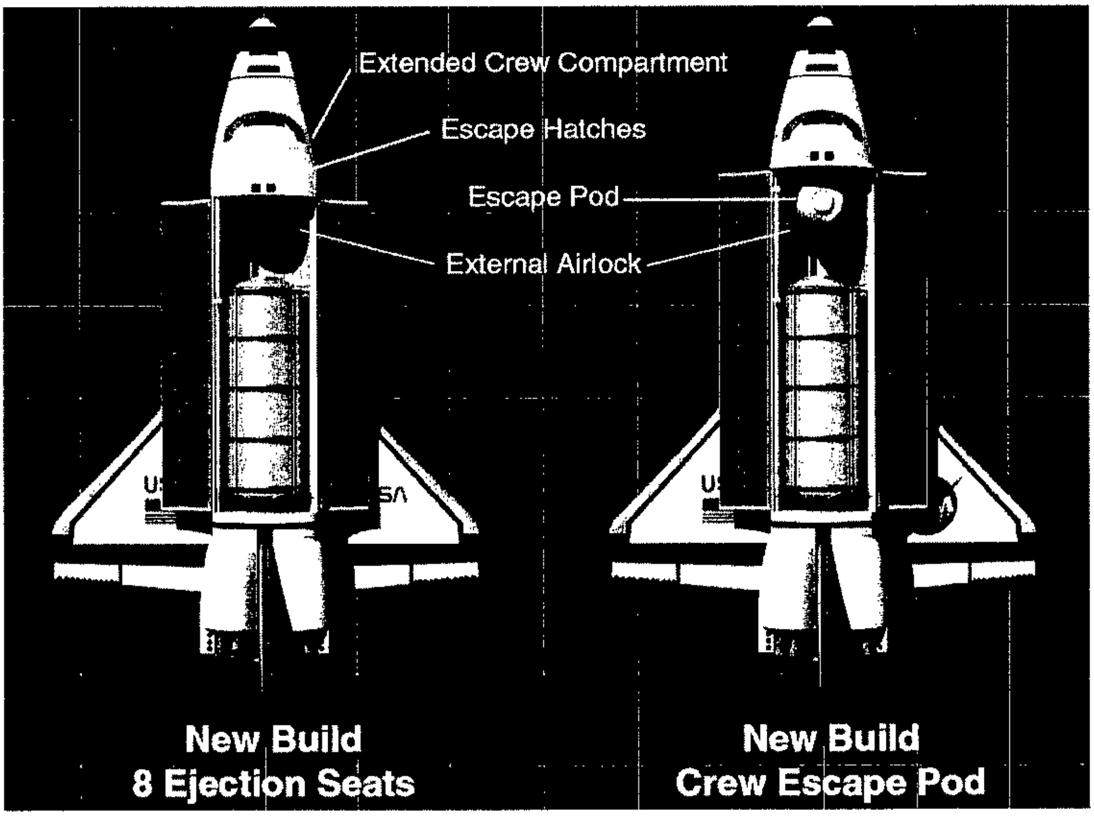


FIGURE 14.—Crew escape comparison.

An uncrewed orbiter system was also evaluated. The new avionics system proposed for all of these alternatives would have the increased capability to allow for automation of the ascent and entry functions currently performed by the pilot and commander. The main intent of this new system function was to augment current flights with uncrewed commercial and DOD satellite launches. It was viewed that these missions do not require an on-orbit crew. The Shuttle system could be utilized in this configuration (uncrewed) for general satellite launches. An associated increase in flight rate could result in a significant reduction in per-flight launch cost.

The second important advantage of an uncrewed orbiter system would be as a test platform for future Space Transportation System (STS) evolution or single-stage-to-orbit vehicle technology. New systems could be evaluated during uncrewed missions and then be baselined for use on crewed missions.

The uncrewed concept defined by the study resulted in an increase of 10,000 pounds performance and a shift of the center of gravity 26 inches back. This performance gained would have to be balanced with payload location or "ballast." The orbiter was not dedicated to either the uncrewed or crewed configuration and could be converted between either mode in the normal processing flow.

Subsystem Improvement Descriptions

Thermal Protection System

The flight history of the Space Shuttle has conclusively demonstrated the operational effectiveness of the existing orbiter thermal protection system. However, several design and materials improvements have been identified that have the potential to significantly reduce orbiter thermal protection system processing requirements and costs.

Tile damage from the normal flight environment, runway debris impacts, and raindrop impingement can be reduced by utilizing a thicker, tougher densification coating known as toughened unipiece fibrous insulation (TUFI). The TUFI is compatible with the current LI–2200 and FRCI–12 tiles, as well as the advanced HTP and AETB tile substrates. The TUFI, which is a highly porous coating, may simplify tile rewaterproofing operations by enabling the direct absorption of a spray-on waterproofing agent through the coating to the tile substrate, an attractive alternative to the current procedure of individually injecting tiles with DMES.

An advanced organic blanket consisting of polybenzimidazole (PBI) felt has been proposed as a replacement for felt reusable surface insulation (FRSI). The PBI has a reuse temperature limit of 900+ °F. Two advanced ceramic blankets—tailorable advanced blanket insulation (TABI) and composite flexible blanket insulation (CFBI)—have been proposed as replacements for AFRSI. The TABI is an integrally woven fabric, while CFBI consists of a multilayer assembly of foils and fabrics sewn together into a blanket. Both TABI and CFBI can be reused without replacement below temperature limits of approximately 2,000 °F.

Because tile removal is required in order to replace filler bars charred by high-temperature gap flows, the elimination of filler bars through the use of full-footprint SIP should significantly reduce thermal protection system maintenance time. In areas subject to high temperature gap flows, reusable ceramic Ames gap fillers will be employed.

Thermal protection system technology development programs, involving both high-temperature waterproofing agents and new rewaterproofing techniques, are currently under way at the NASA Ames Research Center (ARC). The ARC is pursuing the development of a "permanent" ceramic waterproofing agent with the goal of matching the reuse temperature limit of ceramic tiles, approximately 2,700 °F.

Orbital Maneuvering System/Reaction Control System

The Retrofit Alternative retained the hypergolic based system, while the New Build Alternative converted to a liquid oxygen (lox)/ethanol-based system.

For the Retrofit Alternative, the study concluded that it would be too difficult to convert the current orbiter fleet to a new on-orbit propulsion system. Instead, the high maintenance rate of the current system and inaccessibility of numerous components would be addressed. The design changes selected were to redesign the primary thruster engine valves, helium quad check valves, helium regulation system, quick disconnects, orbiter main engine (OME) ball valve seals, and aft thruster feedline alignment bellows. The current pilot-operated valves on the primary thruster would be replaced with new direct-acting valves. The seat design would be similar to that of the vernier thrusters, which have a lower failure rate than the primary thruster valves. The expected drop in failure rate would result in lower hardware maintenance costs. Both the helium quad check valve and mechanical regulator components would be replaced with an electronic regulator system installed with dynatube fittings.

The new electronic regulator system would be designed to be propellant insensitive and capable of being fully checked out on orbit. When removal and replacement is required, the dynatube fittings would eliminate tube cuts that can result in small metal chips contaminating the internal system. These metal chips are currently a major cause of excessive leakage rates that are occurring on many orbital maneuvering system/reaction control system helium components. The quick disconnects would be redesigned to be propellant insensitive. The orbiter main engine ball valve seal would be replaced with one that does not leak. The aft thruster feedline alignment bellows would be replaced with flexlines based on the forward thruster design. In addition to the above redesigns, additional access doors would be added to the pods.

The oxygen/ethanol propellant combination was selected because it eliminates the hypergolic servicing infrastructure, reduces the number of KSC-unique fluids by one, fits within the current mold line, eliminates SCAPE suit operations, reduces or eliminates serial processing required by the current orbital maneuvering system/reaction control system, and eliminates a number of causes of orbital maneuvering system pod removal. In addition to the above, the concept selected provides both the same redundancy level and total impulse level that the current orbital maneuvering system/reaction control system provides. It is expected that the operational cost for an oxygen/ethanol based on-orbit propulsion system will be significantly lower than the current hypergolic-based system.

Avionics

Major changes were made to the communications and tracking system; the guidance, navigation, and control system; and the data management and instrumentation system, thereby reducing the number of line replaceable units. These changes led to the elimination of avionics bays 3a and 3b. This enables the middeck lockers to be relocated to this location, resulting in improved accessibility to avionics bays 1 and 2.

The current Communications and Tracking system was replaced with a more integrated system. The new system resulted in fewer line replaceable units by combining the function of the Communications Security (COMSEC) unit, the network signal processor (NSP), and the transponder into a single line replaceable unit. A new payload computer would combine the functions of the payload signal processor (PSP) and payload interrogator. The power amp and preamp line replaceable unit to the antenna switch would be eliminated. The pulse-code modulation master unit (PCMMU) and payload data interleaver (PDI) functions would be incorporated into the new general purpose computers (NGPC) and payload computer. Increased data transmission rates would eliminate data downlist restrictions, resulting in a single data format and deletion of the FM processor. A self-test capability would be incorporated to provide fault isolation down to the line replaceable unit while installed on the vehicle and down to subassembly during bench-level testing.

The current navigation system would be completely changed to a new inertial navigation system utilizing embedded GPS, embedded radar altimeter functions, differential GPS capability, and IFOG gyros. A GPS antenna grid of six would be added to replace the star trackers. In addition to the star trackers, the inertial measurement unit (IMU)/high accuracy inertial navigation system, tactical air navigation (TACAN), microwave scanning beam landing system (MSBLS), accelerometer assemblies, and rate gyro assemblies would be eliminated.

The data management and instrumentation system would be upgraded to state-of-the-art computers. The improved general purpose computers would incorporate fiber optic cables for coupling to the multiplexer/demultiplexers (MDM's). Both the output/input recorders and mass memory unit (MMU) would be changed to optical storage with the MMU installed in the general purpose computer. The multifunction electronic display subsystem (MEDS) that is currently under design would also be incorporated. The MDM's would be redesigned to allow for individual cards to be replaced while still installed on the vehicle. The overall avionics heat load would be reduced and would allow avionics to be totally cooled by air purge only during all ground turnaround operations. A dedicated ground-located general purpose computer (e.g., ground brain) would be capable of connecting directly into the MDM's and either receive instrumentation data or command other subsystems without the flight general purpose computers on-line. Finally, the backup flight software would be eliminated.

Orbiter Mechanical and Electrical Power Systems

Evolutionary improvements for the orbiter mechanical and electrical subsystems were selected because of their ability to reduce operations cost and improve system safety in the following areas.

- Hazardous ground operations associated with servicing the auxiliary power unit (APU) hydrazine propellant and the high-pressure hydraulic systems.
- Ground operations associated with handling and disposing of toxic hydrazine propellants and hydraulic fluids.
- Flight safety issues associated with the hydrazine auxiliary power units and hydraulics.
- Excessive cycling of the orbiter systems to support ground checkout.
- Repair and replacement of fuel cells due to their limited life.
- Repair and replacement of electrical power distribution and control (EPDC) line replaceable units.
- Repairing accidental damage to electrical wires which occur during ground operations.

An electric auxiliary power unit (EAPU), using high power density fuel cells (HPDFC) for power, was determined to be the most cost-effective replacement for the hydrazine auxiliary power units for the Retrofit Alternative. A modified water spray boiler (WSB) was used for cooling the HPDFC's. For a new-build orbiter, electro-mechanical actuators were selected to replace the auxiliary power units and hydraulic system using high power density fuel cells to supply electro-mechanical actuator electrical power.

The existing fuel cells would be replaced with the long life fuel cell with single-cell instrumentation. The new fuel cells would have a lifetime five times longer than the current fuel cells. The improved instrumentation and increased life would result in reduced line replacable unit removal and replacement (R&R) costs and associated logistics costs.

Redesigned hybrid device controllers (HDC's) would be resettable and would reduce the number of HDC removal and replacement occurrences. A redesigned load controller assembly (LCA) would also be incorporated which would permit for HDC replacement without load controller assembly removal from the orbiter.

The ability to provide power to selective components on the orbiter would be implemented in both design alternatives to varying degrees. Both alternatives would incorporate a dedicated instrumentation power bus and conditioning equipment for selected instrumentation, multiplexer/demultiplexers, and signal conditioners. The electro-mechanical actuators for the new-build orbiter would be powered and controlled through ground support equipment to facilitate ground processing. These improvements would significantly reduce the amount of operating time on orbiter components, thereby increasing the mean time between repair.

Finally, protective covers would be provided for orbiter wire bundles that are located in frequently accessed areas and bundles would be rerouted for easier access. This modification would reduce wire damage that occurs during ground operations.

Environmental Control and Life Support System

Quick disconnects would be installed on high-maintenance components within the Freon™ and water (H_2O) coolant loops, allowing for removal and replacement without requiring a complete deservice of the coolant system. In addition, built-in test (BIT) equipment would be added for the radiator, ammonia, and flash evaporator system controllers, eliminating the need for drag on ground support equipment in the Orbiter Processing Facility (OPF). Midbody and aft cold plate thickness would be increased to reduce damage done to cold plates during line replaceable unit removal and replacement.

The current waste compartment system (WCS) must be removed from the orbiter and shipped to the Johnson Space Center for cleaning and refurbishment after each flight. The WCS developed for the extended duration orbiter (EDO) would replace the existing WCS on all vehicles. The new WCS uses a compactor/canister stowage concept, and does not need to be removed from the orbiter for cleaning and refurbishment.

Relocating the H_2 separator into the midbody area would eliminate vacuum vent inerting ground support equipment and reduce launch countdown manual operations. Safety would also be improved since there would be no H_2 stored within the 2-inch overboard dump line during launch countdown.

The current PSA is designed as two separate pieces, and access to remove these units is difficult. For all vehicles, the PSA would be redesigned for removal as a single unit, which would allow easier removal and reinstallation on the ground.

The new avionics being installed in all vehicles only require cold plate cooling. Therefore, avionics bay 1, 2, and 3 heat exchangers (HX's), six associated fans, and the inertial measurement unit (IMU) heat exchanger and fan can be eliminated.

The ammonia boiler system would be replaced with a cryogenic boiler system on new-build vehicles. This system would provide cooling at low altitudes, through landing and rollout. This system reduces the number of fluids required by the orbiter and eliminates hazardous operations associated with ammonia.

It has been determined that purge air directed through the payload bay provides sufficient cooling after landing. Therefore, the requirement for the 570-0508 cart at the runway can be eliminated. Elimination of this requirement results in fewer operations at landing and a reduction in maintenance of ground support equipment.

Currently, the extended memory unit (EMU) Personal Life Support System(PLSS) water purity requirements are higher than what can be provided by the orbiter. The EMU PLSS design will be changed to allow it to use the orbiter's water supply in its sublimator. This will eliminate 2 weeks of water polishing time at Kennedy Space Center after each extravehicular activity (EVA).

Structural System

For new-build vehicles, aluminum-lithium (Al-Li) would be substituted for aluminum where practical. This will result in a 3,900 pound weight savings over the current orbiter structural mass, which would offset weight increases resulting from design enhancements in other areas, as well as increase payload capability.

The current boron-aluminum (B-Al) midbody struts would be replaced with a more robust material to reduce their susceptibility to damage by technicians working around them. Currently, the midbody struts are being replaced with aluminum struts on an attrition basis. For retrofit vehicles, this would continue until all struts are replaced, resulting in a net weight increase of 200 pounds per orbiter. For a new-build vehicle, Al-Li will be substituted for the B-Al alloy, resulting in a net weight increase of about 180 pounds per orbiter.

The rudder speed brake (RSB) inner panels of the current orbiter fleet are susceptible to corrosion and, therefore, require frequent inspection. Removal and subsequent reinstallation of these panels to make repairs is difficult and time consuming. A design change to eliminate this problem would be implemented on all vehicles, reducing inspection requirements, material costs, analysis time, and precluding the need for reapplication of sealant.

The flipper door system is particularly difficult to service because of its complex design. Both the retrofit and new build vehicles would replace the flipper door system with a wing extension incorporating a piano hinge for wing access requirements. Incorporation of this new design would reduce the maintenance time required to service the wing/elevon cavity, as well as reduce weight.

For a new-build vehicle, the size of the current access ports to the aft compartment would be increased to approximately four times their current size. This would enhance installation and removal of ground support equipment, and allow more technician access at a given time. Also, with less assembly of ground support equipment inside the aft compartment required, accidental damage to components can be reduced. Access ports for other frequently serviced areas will be built into new vehicles, as well, to reduce maintenance and inspection time.

For the retrofit vehicle, access ports will be added to the orbital maneuvering system pods, providing easier access to the most frequently serviced internal components. This will allow the orbital maneuvering system pods to remain on the vehicle for certain inspections and maintenance.

Currently, hot spots seen on the orbiter mid-fuselage lower skin during reentry are handled through the use of RTV heat sinks. For new-build vehicles, the design of the mid-fuselage lower skin can be improved so that RTV heat sinks will not be required, resulting in a weight reduction of 220 pounds.

One concept for crew escape is to provide ejection seats located on the flight deck. In order to provide for this, the crew module would have to be extended 4.5 feet into the payload bay.

Main Propulsion System

Over 36 improvements to the main propulsion system were suggested by the members of the Option 1 team. Half of the implementations were selected by the both the Retrofit and New Build Alternatives. The hardware improvements fell into two categories: improved system operability and items that could be classified as preplanned program improvements.

Modifications to the main propulsion system include component changes, deletions, and additions. Only the outboard LH_2 and LO_2 manifold fill and drain valve assemblies were deleted. New components include leak check/purge ports between the GHe interconnect and the check valves, instrumentation for LH_2/LO_2 fill/drain and LH_2 recirculation system, purge ports to facilitate orbiter GH_2/GO_2 system welding operations, protective covers for flex hoses, filters for the inlets/outlet of the LH_2 and LO_2 manifold relief pre-valves (6) and inboard fill/drain relief valves, and fill/drain and pre-valve inspection ports. Several components would be redesigned including the helium check valves, LH_2/LO_2 relief valves, and the K-seals on rough finished fittings. The foamed-in-place insulation on the engine interface would be changed to precast insulation.

Operational changes would also be approved for the main propulsion system. These changes include provisions for orbiter flange lapping tools and certification of the SPC and/or NSLD to perform required lapping in the field instead of having to return to the vendor, a centralized new vacuum jacket readout panel and vacuum jacketed line repair techniques, extended certification on the external tank/orbiter umbilical joint line assemblies, particle induced noise detection (PIND) testing on valve position switches, and extended certification on limited life temperature probes.